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ERRORS IN ESTIMATING STREAM DISCHARGE IN SMALL HEADWATER CATCHMENTS: INFLUENCE ON INTERPRETATION OF CATCHMENT YIELDS AND INPUT - OUTPUT BUDGET ESTIMATES

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ABSTRACT

The relative uncertainty in estimating stream discharge and its influence on interpretation of nutrient yields and budgets in small headwater catchments of the southern Precambrian Shield were determined. Data available for two catchments and two subcatchments were used to assess the relative uncertainties associated with estimating stream discharge and nutrient yield determined by 1) integrating discrete discharge measurements, 2) correlation techniques, and 3) prorating areal runoff within the subcatchments. This information is used to evaluate the importance of such uncertainty to water and chemical budgets, as well as to assess the acceptability of prorating areal runoff for streams within gauged subcatchments during periods where stream discharge was not continuously monitored.

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INTRODUCTION

Quantitative estimates of water and elemental fluxes or yields are an important prerequisite for biogeochemical studies. It is often economically and logistically impossible, however, to install and maintain the necessary stream gauging equipment to accurately monitor discharge from all streams. Consequently, correlation techniques or the prorating of areal runoff have been used in catchment studies to extrapolate from information garnered for gauged catchments to ungauged catchments (Clark and Bruce 1966, Devito et al. 1989, Fisher and Likens 1973, Meyer and Tate 1983 and Naiman 1982). The application of these techniques to mass balance studies is limited, however, by errors inherent in measuring discharge, large variations in regression error estimates and uncertainities in water distribution in unsaturated and ground water zones. Knowledge of the magnitude of these errors is required to accurately calculate annual and monthly water and nutrient mass balances when assuming uniform runoff and prorating runoff on an areal basis to and from small catchments.

In mass balance studies, the residual of the budget is composed both of unmeasured components, and inherent error in the measured components. The magnitude and direction (positive or negative) of the component is often of prime importance in these studies, necessitating the need for an estimate of uncertainty in the measured component (LaBaugh and Winter 1984). Winter (1981) stressed the need for reporting uncertainties of water yields and provided an in-depth analysis of errors associated with water yields and their influence on interpreting lake water budgets. Since nutrient budgets are derived from water

volume and nutrient concentration, uncertainties in either can result in large biases (LaBaugh and Winter 1984). Despite the large number of studies reporting chemical yields and budgets, associated errors are infrequently reported or used in interpreting of residuals (Elder 1985, Dodds and Castenholz 1988). Reporting measurement error is imperative when comparing the chemical yields of two or more catchments or when interpreting the residual of input-output mass balances.

This study attempts to, 1) provide estimates of the precision and accuracy of stream discharge measurements in small headwater catchments of south central Ontario, and 2) to determine the significance of this error when calculating nutrient yields and budgets by integrating discrete measurements, using correlation techniques and by prorating equal areal runoff.

Long term monitoring of stream and tributary chemistry has been conducted in a number of small headwater catchments in central Ontario (Dillon et al. 1986). Unfortunately, monitoring of stream flow is restricted to the mouth of most catchments. Due to the characteristic shallow surficial till and largely impermeable bedrock, factors conducive to uniform runoff, assumptions of uniform areal runoff have been made (see Devito et al. 1989). The similarity in seasonal and annual runoff from a number of headwater catchments supports this (Scheider et al. 1983); however, the assumption has not been directly tested. Data available for two subcatchments and two gauged microcatchments on the Precambrian shield are used to assess the relative errors associated with estimating stream discharge and nutrient yield determined by, 1) integrating discrete discharge

measurements, 2) correlation techniques and 3) prorating equal areal runoff. These will be used to evaluate the importance of such errors to water and chemical budgets, as well as assess the acceptability of prorating runoff to construct long term nutrient budgets within subcatchments in this region of central Ontario where chemistry alone is monitored.

STUDY AREA

The wetlands and microcatchments are located in two lake subcatchments, Harp Lake subcatchment #4 (Hp 4; 45° 23'N, 79° 08'W) and Plastic Lake subcatchment #1 (Pc 1; 45° 11'N, 78° 50'W). The area is covered with thin deposits of Pleistocene glacial till with exposed bedrock, overlaying Precambrian metamorphic silicate bedrock. Geological and physiographical characteristics of the two study subcatchments and microcatchments are shown in Table 1. In Harp 4, the depth of overburden ranges from >10 m of sand near the stream mouth and north east corner of the subcatchment, to <1 m at the upper reaches. The overburden in Plastic 1 averages <1 m. A detailed description of climate regime is given in Scheider et al. (1983). Aspects of the physiography, geology, and geochemistry of the area and for specific watersheds have been reported (Girard et al. 1985, Jeffries and Snyder 1983, Dillon et al. 1991, and Devito et al. (1989).

METHODS AND MATERIALS

Hydrometeorology

Precipitation and air temperature data for 1982 to 1988 were obtained from meterological

stations located within 1 km of each subcatchment (Locke and de Grosbois 1986). Water levels where measured at staff gauges and wells in Hp 4 beaver pond and Pc 1 swamp on a weekly to daily bases.

Streamflow at the mouth of Hp 4 and within Pc 1 at Pc 1-08, has been measured continuously at hydrologic gauging stations as described by Scheider et al. (1983) and Locke and Scott (1986). A plywood 90° v-notch weir and stilling well were constructed at Hp 4-13 for the period May 1987 to June 1988. For the period March 1987 to June 1988, instantaneous discharge of the inflow streams to Hp 4 beaver pond and Pc 1 swamp were measured at flumes constructed of plywood and plastic sheeting, on an approximately weekly basis, but more frequently (often daily) during peak flow.

Mean daily discharge (MDD) data were calculated either by 1) stage - discharge relationship developed at calibrated weirs to convert continuous water level records (BEST) into a discharge record, 2) prorating areal runoff (PRORATE) per unit time of a gauged catchment of known area (Devito et al. 1989), 3) regressing instantaneous discharge (REGRESS) at the stream of interest with discharge at a calibrated weir, or 4) linear integration (INTEGR) of instantaneous discharge measurements taken at discrete times (Scheider et al. 1979).

Water Chemistry

Precipitation and water sampling was carried out as described by Locke and Scott (1986).

Chemical analysis methods used by the OME laboratories and by the author are outlined in Table 2. Stream samples were taken daily to weekly according to discharge. Sampling and analytical variations in stream and deposition samples were determined herein and as part of data quality control (Locke 1985, 1988).

Wetland Water and Chemical Budget

A general water and chemical budget equation for Hp 4-bp and Pc 1-sw has been described in detail by Devito and Dillon (1992a,1992b). The water budget equation is:

$$P + U_i + \Sigma S_i - E - S_o \pm \Delta W = 0 \pm e \qquad (1)$$

Inputs include stream inflows (S_i), precipitation (P) and unchannelized or ungauged runoff (U_i). Both subsurface and diffuse surface flow from ungauged areas adjacent to the pond were combined into ungauged (U_i) runoff. Outputs include stream outflow (S_o), evapotranspiration (E) and change in storage (ΔW). The inputs should balance outputs $\pm$ measurement error (e).

Deep ground water inputs and outputs were assumed to be negligible. For water storage, change in volume of the pond was assumed to be constant with depth. The specific yield (SY) of peat in Pc 1-sw was assumed to be 0.5 (Boelter and Verry 1977). Potential evapotranspiration (E) was estimated from Thornthwaite's (1948) equation. Chloride budgets were measured as a check on hydrologic budgets.

For this study waterborne nutrient retention (RT) was calculated from inputs which include

bulk atmospheric deposition (P), stream inflow (S_i), unchannelized or ungauged inflows (U_i) and outputs as stream outflow (S_o):

$$P_i + \Sigma S_i + U_i - S_o = RT \pm e \qquad (2)$$

Both wet precipitation and dry deposition are incorporated into P. Subsurface and diffuse surface inflow from areas adjacent the wetland are combined in U_i on a monthly basis.

Atmospheric deposition was calculated as described by Locke and de Grosbois (1986). Reactive phosphorus measurements in bulk deposition were not made, but were previously determined to be 34% of TP deposition (Dillon and Reid 1981).

Stream load was determined by integrating the estimated daily average discharge over each sampling period and multiplying the total volume of water by the nutrient concentration at the midpoint of each time interval (Scheider et al. 1979). Nutrient yield originating from ungauged areas adjacent the wetland was estimated using mean monthly volume - weighted concentrations of nearby streams and prorated monthly runoff volume.

Water volumes and nutrient yields for each component were calculated on a monthly basis and incorporated into each month's budget. Annual budgets were determined by addition of the monthly budgets for the hydrologic year June 1 to May 31. Total organic nitrogen (TON) and total unreactive phosphorous (TUP) were determined by subtracting the mass of NH_4-N from TKN and TRP from TP for each month, respectively. Total nitrogen was determined by adding NO_3 and TKN.

Gross export of each nutrient from the wetlands was reported as mass per unit area per unit time. Absolute retention (RT) was calculated as:

$$RT = (\text{total inputs} - \text{total outputs}) / \text{wetland area},$$

Percent retention (%RT) as:

$$\%RT = ((\text{total inputs} - \text{total outputs}) / \text{total inputs}) * 100.$$

Error Estimates

Wetland Budgets

The residual of the nutrient budget equation represents the net error associated with measuring the components in Eq. 1 & 2 together with the sum of the unmeasured components. The variance of the water budget calculations can be used to approximate the magnitude of the net error. In this study, the errors associated with each component of the budgets were assumed to be random and normally distributed. Determining the distribution of estimates and their errors was not attempted in this study. Some of the potentially important unmeasured and systematic errors are identified and discussed later, but are not included in the error analyses. In addition, the accuracy of any estimate is impossible to determine because the true value cannot be measured due to the lack of control in any realistic field situation. The following variance estimates, therefore, must be considered as only the precision of water and nutrient budget estimates, representing measurable random sampling and analytical variation in estimates of water volumes and chemical concentration.

The variance of water budget calculations was calculated, as described by Winter (1981), to

obtain the standard deviation where:

$$S_T^2 = S_P^2 + S_U^2 + S_{Si}^2 + S_E^2 + S_{SO}^2 + S_{\Delta W}^2 \tag{3}$$

where i=1 to n, the number of inflow streams (S_i) and S_T is the SD of the total monthly water budget. All the measurement errors are or can be assumed independent and covariance terms are not included (Winter 1981). To obtain S_T^2, total monthly water volumes were multiplied by their associated fractional error (c.v.) and then squared and summed.

Errors in estimating the nutrient loads of the components in Eq. 2 involve both uncertainties in estimating water volume and the nutrient concentration. The variance of all products in this study was approximated as (Mood et al. 1974):

$$VAR(X,Y) \simeq u_x^{2}*VAR(Y) + u_y^{2}*VAR(X) + VAR(Y)VAR(X) \tag{4}$$

The variance for each component was calculated using Eq. 4 where: X is water volume, Y is the concentration of a given parameter in that volume. Absolute value of VAR was determined and VAR(X) and VAR(Y) by the multiplication of the water volume or concentration with percent error (c.v.) and then squared.

S_T^2 for the nutrient retention estimates were calculated using Eq. 3. To obtain S_T^2 for TN, TON, TIN and TUP retention estimates the variance associated with the parameters used to calculate each mass were summed. The variance associated with nutrient mass was determined for each time interval and summed to produce either seasonal or annual values.

Measured or literature estimates of c.v.s associated with determining stream flow (S_i and S_o) and ungauged or unchannelized flow (U_i) are outlined in Table 3.

Errors associated with measuring precipitation depth were not determined directly. Precipitation depth is recorded daily from gauges which stand 1 m above the ground with wind shields; thus, the % error of the coefficient of variation (c.v.) due to instrumentation error in total precipitation is about 5% per month (Winter 1981). Regionalization of the data collected at the gauge sites into monthly rainfall rates for the study area probably does not have a c.v. greater than 5% (Huff and Schickedanz 1972). The gauges were within 1 km of the wetlands with a total gauge density for estimates of <1 gauge in 10 km^2; thus, monthly precipitation depths have c.v.s associated with areal averages of about 20% (Winter 1981). Taking all these factors into consideration, the c.v. associated with estimating monthly precipitation depth are estimated at 21%.

The range of uncertainty for determining stage for the wetlands was ±2 mm. The c.v. associated with estimating the area of the wetlands and catchments from air photos and topographic maps are estimated to be ±10%. Uncertainties in estimating SY of a heterogeneous peat with a microtopography probably dominate the error term in Pc 1 swamp and are assumed to be ±50%.

Analytical and sampling errors associated with determining stream water and bulk deposition chemistry of discrete samples are reported in Locke (1988) and Devito (1989). Errors associated with volume weighted concentrations are assumed equivalent to analytical

and sampling errors. Errors associated with average monthly volume weighted concentrations must be less because estimates are determined from 4 to 12 samples. A compensatory increase would be expected due to errors associated with inadequate sampling of temporal variations in stream concentration. Errors associated with temporal variations in nutrient concentration were not included in this error analysis. However, Scheider et al. (1979) report little effect of varying sampling frequency on the estimates of phosphorous loads from streams in the Harp Lake catchment. The concentration of elements measured in this study were relatively constant with discharge (Devito 1989) and temporal variation in nutrient concentration is small. Concentrations of NH_4 and NO_3 are an exception. However, during 1987/88, sampling frequency was regulated according to flow and samples were collected daily during peak flows. Thus, errors associated with volume weighted concentrations are assumed equivalent to analytical and sampling errors.

Method Comparison

Errors associated with different methods of estimating stream discharge are defined as the difference between the results of a given calculation method (PRORATE, REGRESS, INTEGR) and the result of the best method, which is defined here as continuously recorded stage measurements (Herschey 1974):

$$\text{St. Error (standard error)} = [\Sigma(\text{obs}_i - \text{pred}_i)^2/\ \text{n-1}]^{1/2} \qquad (5a)$$

$$\%\ \text{Error (average percent error)}$$

$$= \{\Sigma[(\text{obs}_i\text{-pred}_i)/\text{obs}_i * 100]^2/\text{n-1}\}^{1/2} \qquad (5b)$$

Errors associated with estimating MDD with regression was determined using Eq. 5. Prorating estimates had an error of ±10% associated with estimating catchment area. Errors associated with estimating discrete discharge measurements (INTEGR) were determined from 3 to 5 replicates taken at measurement period. Errors associated with MDD are summed for monthly and annual values. Errors associated with measuring instantaneous discharge (INTEGR) using the Ott meter include systematic and random errors and where derived from empirical equations described by Herschey (1974).

RESULTS AND DISCUSSION

Uncertainties in Budget Components

Catchment Water Yields

The coefficients of variation for instantaneous discharge and MDD measurements of runoff used in calculating the water budgets for Hp 4-bp and Pc 1-sw are shown in Table 3. Errors associated with instantaneous discharge measurements appear to be around 5% for all rates of discharge (Table 3). The error may be much greater for some streams where measurement is more difficult to perform, such as small streams with poorly defined channels (Pc 1-b) or were beaver activity alters the channel (Hp 4-18). Continuous stage recording with an accurate stage discharge curve is assumed to give the best estimate of stream discharge. Measured errors in instantaneous discharge plus the percent deviation in stage - discharge curves for the 4 weirs ranged from 18 to 23% (Tables 3 & 4) and errors associated with MDD appear to be about 20%. Errors associated with estimating and

recording stage were assumed to be compensated by the number of instantaneous measurements taken in one day. All errors were assumed random, resulting in an estimated precision of less than 10% per month and less than 5% per year for the two gauged weirs. Winter (1981) reports slightly greater error of about 10-15% per month and 5-10% per year using the best methodologies.

The uncertainties in measured discharge in this study must be higher than we had calculated because all the possible errors in estimating discharge were not determined. Runoff estimates at each of the weirs are subject to both random and systematic errors which are often difficult or impossible to measure (Herschey 1973, Winter 1981). Assuming these are only random errors, results in a decrease in variance of estimates over time or with an increase in sampling. Systematic errors (i.e., Channel bias, weir leakage) may result in maintenance of relative error or an increase in absolute error over time or with an increase in the number of measurements.

The best fit linear and non-linear regression models for estimating stream discharge from a continuously monitored flume within the same subcatchment are shown in Table 5. Although the fits of the regression models are very good ($R^2 > 0.9$) % ERR for MDD may be very high, ranging from 47 to 114%. Annual errors of water yield estimated by regressing discharge and prorating are larger than gauged estimates, being 9 and 10% respectively. Winter (1981) expressed caution in interpreting discharge estimated by correlation because of the possibly high and widely variable estimates of error of regression.

Catchment Chemical Yields

The influence of uncertainties in stream flow volume on chemical yield may be evaluated from annual estimates of a number chemical yields from the two catchments (Table 6). Differences in the errors associated with chemical yields for a given catchment will depend on sampling and analytical variation for each chemical. The errors in annual chemical yields of the gauged streams ranged from 2 to 14%, median 4%. For the inflow volume estimated by regression, % ERR estimates of annual yields ranged from 6 to 18%, median 8%. The % ERR in annual yields for prorated stream volume ranged 9 to 45%, median 12%. Although there are very few data to compare, these estimates of uncertainty seem reasonable. Elder (1985) reported similar error of annual yield estimates for Apalachicola River wetland system, calculated from the sum of squares component SD, of 5 to 6% for N and 8 to 9% for P. Dodds and Castenholz (1988) estimated the variance from the range of estimates for spring water and runoff inputs and outputs in an Oregon stream. For TN the % SD from the mean ranged from 8 to 18%.

Influence on Budget Residuals

Although there are limited data, the uncertainty in estimating the water budget of Hp 4-bp and Pc 1-sw were 6 and 11% of the total inputs, respectively. This would be 12 to 22% at 95% confidence interval (2SD). Winter (1981) sites a hypothetical error analysis of a water budget for a New England lake which has relative input and output water volumes similar to this study. The errors for annual estimates of precipitation and stream flow in Hp 4-bp

and Pc 1-sw are comparable but slightly lower than those expected using the best methodology. Error estimates of ungauged inputs were greater than those related to commonly used methodologies. Errors in prorating annual streamflow were intermediate between errors related to the best and commonly used methodologies described by Winter (1981).

The measurement errors of the chemical budgets ranged from 5 to 11% (median 8%) and 4 to 35% (median 13%) for Hp 4-bp and Pc 1-sw, respectively. Although there is a limited number of budgets for 1987/88 it is possible to roughly estimate the relative residual which can be considered significant in a typical study. Combining the chemical budget uncertainties for both wetlands, the median SD is 10%. If comparable methodologies are used to determine input-output budgets on a system with similar chemical fluxes, a retention of at least ±20% is necessary to be interpreted as significantly different from zero with 95% confidence (2 SD).

The measured errors for the waterborne budgets of these wetlands must be considered as low estimates of error. Errors associated with runoff estimates are probably greater than indicated. There is evidence that precipitation collectors introduce systematic errors which are probably not consistent with variations in precipitation volumes (Winter 1981). Further biases are probably introduced when determining bulk deposition (Dillon et al. 1988). There may also be increased error due to inadequate sampling frequency of stream chemistry, although these would appear to be minimal (Scheider et al. 1979).

Errors associated with chemical budgets are so infrequently reported that it is difficult to determine if the errors associated with each component are reasonable. The hydrologic and chemical characteristics of these two systems are similar to numerous lake, catchment and wetland systems in the study area and other geographical regions in which runoff dominates chemical inputs and outputs. Given the measured uncertainties associated with the budgets provided in this study, interpretation of mass balances with moderate to low retention efficiency, especially if interpreting the difference between large input and output, should be done with caution.

Spurious Correlations

The influence of uncertainties in the analysis of nutrient budgets in terms of hydrologic characteristics is shown in Figures 2 and 3. Annual TP and TN retention vs. runoff for 5 wetlands from 1983/84 to 1987/88 show slight increases in retention with increases in runoff. However, all of the waterborne TN and the majority of TP budgets were within $\pm 30\%$ retention efficiency. Most of the budgets where calculated from water volumes estimated by prorating areal runoff and may not represent significant differences. Of note is the increase in magnitude of the deviation from zero with runoff. This is expected, because at a given concentration the calculated mass increases with discharge. Such a trend may be explained by the error associated with estimating the water volume and concentration of inputs and outputs. Figure 3 shows the relationship of RT with runoff, where input and output concentrations were randomly selected from a flat distribution ranging 10% about a mean which was, in this case, 10 for both inputs and outputs. Assuming a net chemical

balance in the wetland (e.g., volume weighted input concentration = output concentration), the inputs and outputs of the study wetlands are large relative to the difference. Small biases in measurements of water volume or concentration of either inputs or output thus can result in large absolute deviations in residual estimates.

Any observable relationship may simply be spurious. Because runoff volume is a component of mass balance calculations, analysis of nutrient budgets in terms of hydrologic characteristics are complicated by potential spurious self-correlation (Kenney 1982). Assuming inflow equals outflow, the relationship of RT, estimated from random input and output concentrations between 1 and 10, vs. discharge is centred around zero. Thus, there is no apparent spurious self-correlation when comparing RT with monthly runoff (Fig 3). The highly spurious relationship between total inputs and retention is shown for comparison. However, runoff volumes are a component of RT calculations and intuitively a spurious relationship should result between RT and runoff (Kenney 1982). The analysis is overly simplistic. Exerting specific criteria to inflow and outflow which more accurately depict real situations may reveal potential statistical problems. This deserves further work in view of the number of studies relating biogeochemical processes to hydrologic phenomena. Potential problems associated with spurious correlations or errors in estimating mass balances may result in serious misinterpretations of data, and this problem is not often appreciated.

Comparing Methods of Estimating Stream Discharge

Catchment Water Yield

The results of calculating daily discharge for Hp 4-13 and Pc 1-08 using the four techniques are given in Table 7. The average MMD for the three extrapolation methods were similar to and correlated well with daily discharge determined by continuously recorded stage ($r>0.9$). For Hp 4-13 and Pc 1-08 the slopes and intercept for REGRESS and PRORATE vs. the BEST method were approximately 1 and zero, respectively. Estimating MDD discharge by REGRESS appeared to give the best comparison and produced the lowest absolute standard error of the three techniques. Estimating MDD by INTEGR method deviated the most with a slope significantly less than one and intercept greater than zero. However, the absolute S.E.s for all three methods are within the range of errors associated with the stage discharge relationship (Table 4). The % errors are considerably greater, and range from ±28 to >200% (Table 7). Integrating discrete discharge over time gave the lowest % ERR (67%) at Hp 4-13 and prorating unit areal runoff gave the lowest (±28%) at Pc 1-08.

Errors in monthly discharge are similar to daily discharge (Table 8). Integrating the discrete data gave the smallest % ERR (20 and 27%) with progressive increase in % ERR with prorating and regression techniques. This is opposite to the errors in estimating annual discharge (Tables 8 & 9). The regression technique gave the smallest error (2 and 3%), followed by prorating (-1 and -9%) and integrating discrete discharge (-6 and 7%). Annual runoff estimates for 1987/88 calculated using the three non-calibrated techniques are within

±10% of the runoff determined by continuous discharge estimates at Hp 4-13 and Pc 1-08 (Table 8). Much of the variation observed between annual as well as monthly discharge can be accounted for by estimates of precision error for each technique.

The distribution of % ERR is skewed with the largest error associated with lower flows. There is a large reduction in % ERR in the regression and prorating estimates when periods of low flow are excluded. Plotting the monthly discharges calculated by continuous measurements with the other three techniques illustrates a potential systematic bias of estimating daily discharge (Fig. 4). Discharges calculated from continuous measurement during the summer were considerable lower than loads calculated by regression and prorating techniques at both Hp 4-13 and Pc 1-08. The relative and absolute magnitude of the difference was greater at Hp 4-13. Although this period represents 25% of the time, the total volume of runoff for the 3 months represents less than 2% of the annual runoff.

Calculations of monthly discharges by both techniques during other times of the year correspond well with discharges calculated by continuous discharge data. The % ERR was generally within ±5% during April, 1988 when >45% of the annual runoff occurred. Discharge determined by prorating runoff at Hp 4-13 consistently underestimated discharge calculated by continuous measurements during the non summer months, with a % ERR of -8% for April 1988.

Scheider et al. (1979) report a mean absolute error of 12% between annual stream volumes determined from gauged weirs and by integrating instantaneous discharge in a similar study

of 7 catchments on Harp Lake. The percent difference between annual water yields determined from a gauged weir and integrating discrete discharge reported in this study is approximately half (-6 and 7%) that reported by Scheider et al. (1979). In this study, discrete measurements were made every day or second day following rainstorm and melt events and every day for a 3 week period during the snowmelt. Scheider et al. (1979) measured instantaneous discharge on a weekly basis. The accuracy of integrating discrete discharge measurements would increase with an increase in the frequency of measurements. Provided all the major hydrography peaks are sampled, it appears that this technique can approximate stream discharge well. The accuracy of determining daily discharge is also dependent on how representative one discrete measurement is to the average daily discharge. Systematic biases in time of sampling may result in systematic over or under estimates of discharge due to the diurnal flow pattern observed in most streams. Such bias may have resulted in the overestimation of flow at Hp 4-13 and underestimation at Pc 1-08 using this technique. The Harp 4 tributaries were measured primarily during the afternoon while those at Plastic 1 were measured generally before 12:00 hr.

The accuracy of determining discharge using correlation techniques is dependent both on the statistical assumptions and on the assumption of linearity and time invariance inherent to systems analysis (Dooge 1968). Problems in estimating daily or monthly discharge throughout the year are common in using correlation techniques (Winter 1981). The frequency distribution of daily discharge for any hydrologic year is skewed towards lower flows. Relatively few high values exert a large influence on the regression model, determining slope and intercept (Weisberg 1980). Log normalization of the data, which is

suggested (Clark and Bruce 1966), resulted in underestimation of higher daily discharges. Accurate estimates of higher flow values are desirable given that these values make the greatest contribution to the annual runoff; however, small variations in intercept of a regression model can result in a large variation in discharge estimates relative to the observed low flow.

The implied assumptions of linearity and time invariance may restrict the application of correlation techniques in regionalizing runoff. Stream hysteresis and topographic and spatial variation in soil and vegetation, and thus antecedent conditions, can result in spatial variation and strong non-linear and time variant runoff response in a catchment (Anderson and Burt 1985, Dooge 1968). Such conditions greatly increase the variability in relationships and reduce the accuracy of correlation estimates, especially for short term estimates such as mean daily discharge.

Estimates of MDD may be improved by multiple regression of a number of basin characteristics (Deangelis et al. 1984, Riggs 1973) or modelling (de Grosbois et al. 1986, Luxmoore and Sharma 1980). However, this requires considerably more information. Developing separate regression models for low flow conditions (Hardison and Moss 1972, Clarke and Bruce 1966) or utilizing other information such as integrating discrete discharge can reduce such bias. Using discharge estimated by integrating discrete measurement during the summer results in a slight underestimation of annual runoff at Hp 4-13 of 0.463 m (-3%) but reduces the % ERR of monthly estimates from ±200% to ±33%. However, estimates of daily, monthly and annual discharge using regression were often as good or better than

estimates determined by integrating discrete discharge, and regression does not require frequent sampling of every storm or melt event. It is imperative that an adequate sample of high discharge periods be obtained because errors associated with extrapolation are impossible to determine and can be considerable (Weisberg 1980).

Catchment Nutrient Yields

Observed differences in annual and monthly TP yields determined by continuous discharge and by the integration of discrete discharge, regression and prorating were slightly higher than those observed for discharges (Table 10). All three techniques calculated annual TP loads that were within ±10% of TP loads calculated using continuous discharge data at Hp 4-13 and Pc 1-08. Integrating discrete discharge gave the lowest monthly % error for both streams. TP yields from Hp 4-13 determined by regression and prorating had large % ERR (205 and 207%) due to overestimation during the low-flow period. All estimates were within ±40% during higher flows.

Prorating Areal Runoff

Catchment Runoff

As previously discussed, calculating daily and monthly discharge using the PRORATE and the BEST techniques for Hp 4-13 and Pc 1-08 produced similar volumes (Tables 7 & 8), but PRORATE methods did overestimate stream discharges during low flow periods (Fig. 4). Monthly runoff for the entire Hp 4 subcatchment was greater during the summer and lower

during the rest of the year compared to the Hp 4-13 microcatchment. Monthly loads determined by integrating discrete discharge at Hp 4-14, Hp 4-15 and Hp 4-18 from March 1987 to May 1988 shows similar biases observed at Hp 4-13 (Fig. 5).

Differences between annual yields calculated by prorating runoff for the entire subcatchment and continuously recorded discharge at Hp 4-13 and Pc 1-08 were 10 and 1%, respectively. The four calibrated sub- and micro-catchments in this study range in size from 3.45 ha to 119.09 ha but have very similar rates of annual runoff, ranging from 0.432 to 0.476 m (Table 9). The four estimates of runoff have a mean 0.455 with a coefficient of variation of 4%. Independent estimates of annual runoff determined by regression and integrating discrete discharge for Hp 4-14, Hp 4-15 and Hp 4-18 micro-catchments range from 0.404 to 0.507 m representing -7 to 17% of the annual runoff for the entire Hp 4 subcatchment and -11 to 11% of the mean runoff (0.455) for the 4 calibrated weirs (Table 9). Annual runoff from Pc-04 micro-catchment was estimated to be between 0.107 to 0.125 m.

Results from both Plastic 1 and Harp 4 subcatchments indicate that prorating areal runoff estimates annual, monthly and in certain conditions daily discharge well for many of the small headwater subcatchments in the study area. Scheider et al. (1983) found that for catchments in the area, 98.5 to 99.0% of the variation in annual discharge could be explained by catchment area. Fisher and Likens (1973) found that estimates of annual discharge using cumulative catchment area were within ±10% of empirical measurements. Naiman (1982) reports similar relationships for a number of catchments on the Precambrian shield in Quebec. DeAngelis et al. (1984) found that the variation in runoff between a

number of basins in northern Vermont cou!d be adequately explained using only water input (i.e., precipitation).

The accuracy of the prorating technique depends both on 1) the degree of uniformity of runoff throughout the catchment, and the accuracy of 2) measurements of the subcatchment and microcatchment areas, and of 3) the empirical measurements.

Topography, soil depth, vegetation and rainfall are the primary controls of mechanisms generating surface runoff, and their spatial variability will lead to patterns of runoff generation across a catchment (Dunne 1983, Wood et al. 1990). The success of prorating areal runoff will depend on the spatially invariant nature of such controls and the scale at which spatial averaging of these controls is conducted. The scale of the microcatchments and subcatchments used to prorate areal runoff in this study are at the same field scale (10 to 100 ha) distinguished by Dooge (1986) where the global effect of spatially variable properties are roughly equal. The subcatchments in the study area are small enough that meterological variations, such as type, intensity and distribution of precipitation are small. The subcatchments are forested throughout and have relatively uniformly shallow soil depths. Although there is some variability in vegetation type and soil depth within the study catchments, small variations may be tolerated provided they remain constant over time (Blackie and Eeles 1985). Because of the shallow soils, water recharge is relatively small. Mapping of saturated effluent zones in Harp 4 and Plastic 1 during the snowmelt period reveals a relatively extensive and uniformly distributed network throughout the subcatchments (McDonnell and Taylor 1987, Shibitani 1988). All these factor are conducive

to uniform flow and support the application of prorating areal runoff estimates for tributaries within many of the gauged subcatchments. It is difficult to determine if areal runoff may be extrapolated between subcatchments.

Variations in microcatchment aspect and canopy cover indirectly influence runoff and significant spatial variability in snowpack development, timing and duration of snowmelt has been observed in Hp 4 and Pc 1 catchments (pers. obs., Buttle and McDonnell 1987, Shibitani 1988). Soil and depression storage (i.e., beaver ponds and swamps) has resulted in delay of peak hydrography response in some tributary streams in Hp 4 and Pc 1 subcatchments when antecedent soil moisture is low. Depression storage in beaver ponds and swamps is limited, and represent a very small percentage of water flux during fall storms and spring melt when greater than 50% of the annual runoff may occur (Devito and Dillon 1992a,b). Nevertheless, the difference in timing limits the use of simple prorating techniques in short term (i.e., daily) studies.

Runoff from Pc 1 subcatchment was more uniform and showed less seasonal bias than Hp 4 subcatchment. Pc 1 subcatchment is uniformly vegetated with conifers limiting spatial variability in runoff due to vegetation type and distribution. Pc 1 is circular in shape, thus the tributaries meet roughly at the centre of the subcatchment resulting in a similar hydrologic response throughout the entire catchment. The discrepancy in depth and spatial variability of soil would appear to explain the difference in spatial variability of runoff in Pc 1 and Hp 4. The surficial till is very sparse (<1 m) in Pc 1 reducing potential water storage in any region of the subcatchment. The low hydraulic conductivity of the wetland

peat in the centre of the subcatchment results in a relatively high water table limiting water storage and inducing quick flow generation (Devito 1992b). Soil depths at the upper reaches of Hp 4 are considerably less than till deposit near the base of the outflow. Above Hp 4-13 the shallow till and impermeable bedrock are conducive to quick flow responses (Ward 1975, McDonnell and Taylor 1987). Recharge into sandy till near the mouth of Hp 4 would result in a reduction of runoff during high flow as the tills are recharged and higher flow rates during the summer for the entire subcatchment relative to Hp 4-13. This is evident in that the small intermittent and ephemeral streams (i.e., Hp 4-14 and Hp 4-15) typically dry up during the summer while stream flow still occurs at Hp 4-13 and at the mouth of the subcatchment.

In the application of areal runoff estimates within a subcatchment, the discrepancy in soil depth must be considered. Large systematic biases in estimated stream discharge may occur in application of this technique in catchments as small and with as shallow surface till as Hp 4. The uncertainty in estimating discharge by areal runoff may increase as the area of the microcatchment in which runoff is being estimated decreases relative to the area of the subcatchment in which the areal runoff is determined. The ratios of the areas of the Hp 4-14 and Hp 4-15 microcatchments to the entire Hp 4 subcatchment are 1:20 and 1:32. Annual runoff estimates by prorating are very similar to empirical measures of annual runoff, however, monthly estimates can grossly overestimate discharge, especially during low flow period. Microcatchment to subcatchment ratios for Hp 4-14 and Hp 4-15 probably represent the minimum ratios for acceptable discharge estimates using areal runoff.

Much of the variation observed in runoff estimates between catchments can be accounted for by errors in estimating stream discharge and the catchment areas. A c.v. of 4% in runoff estimates between the 4 continuously gauged micro- and subcatchments is similar to errors in measuring annual discharge (3%) and catchment boundaries and areas (5-10%). Errors in measuring catchment areas are systematic. Care should be taken in interpreting hydrochemical studies which compare the elemental yield or flux from 2 catchment outflows when areal runoff is used to calculate stream discharge volumes. Areal runoff grossly overestimated discharge at Pc 1-04. The microcatchment is in relatively flat terrain and streamflow has been observed crossing the microcatchment boundary (this study, Shibitani 1988). This demonstrates the limitation of utilizing areal runoff in flat terrain with non-controlled streams because of the difficulty in accurately estimating the runoff boundary. Although uncertainties associated with the empirical measurement of areal runoff are relatively small ($< \pm 10\%$), they can explain much of the observed variation in runoff between the 4 continuously gauged sub- and microcatchments.

Importance to Water and Chemical Budgets

Estimated % c.v. of monthly water loads calculated for prorating areal runoff for streams in Pc 1, or similar subcatchment, is 18% and for streams in Hp 4, or other larger subcatchments, is 29% (Tables 7 & 8, Fig. 4). Runoff from diffuse unchannelized sources (U_i) may not be directly ascertained. A % c.v. of 30% is suggested in this study (Table 7 & 8).

There is no interpretive difference between water and chemical budgets of Harp 4 beaver pond and Plastic 1 swamp determined by prorating areal runoff and by best estimates of runoff when using the known errors associated with both methods (Table 11).

There is little difference observed between methods during the months with the lowest (July 1987) and highest runoff (April 1988) (Table 11). The best agreement was observed during the highest flow and in the smallest subcatchment, Plastic 1. A majority of the water and nutrient flux occurs during higher flows when runoff is most likely to be uniform throughout the two subcatchments. As would be expected, there is closer agreement between budgets calculated by both methods for the Plastic 1 swamp which is in the smaller subcatchment. Potential bias of prorating runoff during the summer in Harp 4 is reduced because prorating consistently overestimated both the input and outputs to Harp 4 beaver pond. However, monthly budget estimates during the summer should be interpreted with caution. Precipitation inputs dominated the budgets for these particular parameters. The bias of prorating runoff for summer monthly water and nutrient budgets can potentially increase if precipitation or other budget components which are more accurately measured do not dominate the inputs during this period.

Change in storage is not determined in water budgets calculated by prorating areal runoff. On an annual basis, change in storage probably has little influence (<1%). However change in storage represents a significant output seasonally during summer drawdown and fall recharge of the wetlands and biases estimates of runoff determined by prorating.

SUMMARY AND CONCLUSIONS

Uncertainties associated with estimating mean daily stream discharge compared with the best method, measurement at a gauged weir, can be greater than 20%. If random errors are assumed, uncertainties at the gauged weir are about 10% of monthly and 5% of annual yields. The uncertainties are probably higher due to unmeasured or systematic error. The errors associated with catchment elemental yields are a little greater.

Due to the number of budget components, the uncertainties associated with nutrient budgets of ecosystems are no less than ±20% of the residuals on an annual basis. The magnitude of the fluxes and the number and type of input and output components of the wetland budgets are similar to a number of other aquatic and terrestrial systems in the southern Precambrian Shield, as well as other geographical regions. The potential magnitude of the uncertainties associated with nutrient budgets should be considered when interpreting budget residuals.

Extrapolating stream discharge data introduces more errors in runoff estimates relative to a gauged weir; however, runoff estimates determined by integrating discrete measurements, correlation techniques and by prorating areal runoff compare well with runoff estimates determined from continuous stage records. All 3 methods were within ±10% of annual water and TP loads. Except for summer low flow periods, the % ERR of daily discharge

estimates relative to estimates determined by continuous discharge ranged from 25 to 124% in both Hp 4-13 and Pc 1-08. However, due to potential systematic bias daily discharge error estimates should not be used over short periods.

With a high measurement frequency during peak flow periods, monthly runoff determined by integrating discrete discharge had a mean % ERR ±20 and 27% at Hp 4-13 and Pc 1-08 (range -71 to 52%, n=24). During periods that were not characterized by low flow, monthly estimates had a % ERR ±33 and 25% using regression and ±29 and 18% using prorating techniques. Regression and prorating techniques grossly overestimated runoff (up to >400%) in the larger Harp 4 subcatchment during the summer low flow period. Because the runoff during this period contributes little to the total annual runoff, estimates of annual runoff were not affected.

The three secondary methods of estimating stream runoff are not equivalent substitutes for stream flow records provided by installed water level gauges combined with stage-discharge relationships. However, the good agreement between runoff estimates calculated by continuously recorded discharge and by prorating within different sized catchments, suggests that prorating can be used profitably to estimate annual and monthly runoff within the study subcatchments and other similar small headwater catchments. The minimal difference observed between estimates determined by integrating discrete discharge and regression do not warrant the extra work needed to provide runoff estimates using discrete measurements. The accuracy of prorating areal runoff depends on the accuracy of delineating catchment boundaries and the degree of homogeneity of the physical characteristics of the catchment.

Regression or integrating discrete discharge probably provide better estimates than prorating if the area used for estimating the unit runoff is large or likewise if the area of microcatchment is small relative to the entire subcatchment. It should be noted that errors associated with any of the extrapolation methods are probably no less than ±20% per month and would be greater when combined with elemental exports. The magnitude of these uncertainties must be considered when interpreting chemical exports in biogeochemical studies.

There was no significant difference observed between annual water and chemical budgets for Harp 4 beaver pond and Plastic 1 swamp estimated by prorating runoff or by using the best estimates of runoff. However, monthly budgets during the low flow periods should be interpreted with caution due to the potential overestimation of water and chemical runoff inputs and outputs.

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Table 1 Morphological and physiographical characteristics of the two study catchments and wetlands.

Catchment	Area (ha)	Slope (aspect)	Grade (%)	Stream length (m)	Range Till Depth (m)	Dominant Vegetation
Harp 4	119.53	NE	5	3826	0-10	1,2
Hp 4-13	61.51	NE	2	1480	0-1	1,2,5,6
Hp 4-18	39.21	NE	4	563	0-1	1,2,5,6
Hp 4-14	3.74	S,SE	11	170	0-1	1,2
Hp 4-15	6.07	S&E	12	188	0-1	1,2,6,7
Hp 4-bp (wetland)	3.80	-	-	-	-	5,6
Plastic 1	23.34	S,SE	5.9	1316	0-1	1
Pc 1-08	3.45	S	9	267	0-1	1
Pc 1-04	5.28	S&E	4	400	0-1	1
Pc 1-a	1.88	E	5	222	0-1	1,3,4,5
Pc 1-sw (wetland)	2.20	-	-	-	-	1,3,4

1 conifers (Pizea morizona, Thuja occidentalis, arix larrzina)
2 deciduous vegetation
3 Alnus spp.
4 Ilex verticulata
5 Sphagnum spp.
6 open water
7 dead tree snags

Table 2 Outline of analytical procedures.

Parameter	Abbreviation	Units	Procedure+	% c.v. Analytical and Sampling Error
total phosphorus	TP	μg/L as P	Acid digestion, acid molybdate colorimetry	8.1
total reactive phosphorus	TRP	μg/L as P	Acid molybdate colorimetry	18.0
ammonium	NH_4-N	μg/L as N	Phenate - Hypochlorite colorimetry	17.8
nitrite/nitrate	NO_3-N	μg/L as N	Hydrazine reduction - Azo dye colorimetry	9.0
total Kjeldahl nitrogen	TKN	mg/L as N	Acid digestion - neutralization and colorimetry	3.4
chloride	Cl	mg/L	Thyocyanate colorimetry	8.1

+ Modified from Stainton et al. (1977)

Table 3 Percent variation of coefficient of variation (c.v.) of daily and monthly stream discharge measurements from March 1987 to May 1988.

Stream Site or Weir	Spot Q (SQ)			Regression (RQ)	Total % St Error	Monthly % Error
	Range L/S	No. Dupl.	Mean C.V.	% ERR#	$= SQ^2 + RQ^2$	1987/88
Hp 4	-	-	5*	21@	22	
Hp 4-13	all	-	4.8+	17@	18	
	<15	42	2.4	-	-	
Hp 4-14	all	47	4.0	L	L	20
Hp 4-15	all	56	5.1	L	L	20
Hp 4-18	-	33	14.2	72	73	
Hp 4-B	all	15	5.6	L	L	20
Ungauged	(area - Hp 4-bp)			-		(U) 30
Pc 1		-	5*	21@	22	
Pc 1-03	-	-	-	P	-	18
Pc 1-08		11	3.2	23@	23	
Pc 1-04	all	25	4.7	-	L	
Pc 1-A	all	22	4.6	-	L	
Pc 1-B	all	1	19.0	-	L	
Pc 1-C	all	5	7.1	-	L	
Ungauged	(area - Pc 1 - A,B,C)			-		(U) 30

+ estimated using Herschy (1973)
* assumed the same as Hp 4-13
@ from stage - discharge curve
# $\sum^{n}$ ((pred-obs/pred)*100)^2/n-1
L linear integration
P prorating unit runoff
Ungauged runoff = 30%/month[1]

Table 4 Stage-discharge relationships.

Weir	Stage (m)	Equation[1]	n	STD Error	% ERR (MOD)
Hp 4	0.0 - 0.500	$Q = 2.131\ S^{1.936}$	220		21
Hp 4-13	0.0 - 0.232	$Q = 1.957\ S^{2.585}$	65	1.10	18
	0.232 - 0.500	$Q = 0.0448 + (1.0515^{1.281})$	14	2.34	
Pc 1	0.0 - 0.126	$Q = 1.559\ S^{2.455}$	205	1.59	21
	0.126 - 0.500	$Q = 0.0096 + (3.158\ S^{1.89})$	81		
Pc 1-08	0.0 - 0.400	$Q = 1.098\ S^{2.318}$	135	2.70	23

Q = discharge m^3/S
S = stage (m)

Table 5 Stream discharge regression equations.

Stream Site	Regress with	Model	n	Adj R^2	St. Error	% ERR
Hp 4-13	Hp 4	Hp 4-13 = 0.052 + 0.562 Hp 4	380	0.981	2.34	48
Hp 4-14	Hp 4-13	Hp 4-14 = 0.005 $(\text{Hp 4-13})^{1.65}_{i+1}$	56	0.917	1.96	47
Hp 4-15	Hp 4-13	Hp 4-15 = -0.240 + 0.118 Hp 4-13	72	0.877	1.72	114
Hp 4-18	Hp 4-13	Hp 4-18 = 0.557 $(\text{Hp 4-13})^{1.03}$	46	0.909	4.32	72
Hp 4-B	Hp 4-13	Hp 4-B = 0.0072 $(\text{Hp 4-13})^{0.872}_{i+1}$	40	0.319	0.643	85
Pc 1-08	Pc 1	Pc 1-08 = 0.043 + 0.140 Pc 1	486	0.914	0.358	59
Pc 1-04	Pc 1-08	Pc 1-04 - 0.731 + 0.776 Pc 1-08	31	0.716	0.910	91
Pc 1-A	Pc 1-08	Pc 1-A - 0.860 + 0.56 Pc 1-08	27	0.525	1.04	104

i = day

Table 6 Combined stream inflow and outflow and estimated uncertainties of Pc 1-sw and Hp 4-bp wetlands. All parameters in $g/m^2/yr$ except TP and TRP ($mg/m^2/yr$) and water (mm/yr).

		Main Inflow		Outflow	
Parameter	Site	Yield ± SD	(% input)	Yield ± SD	(% output)
Water	Hp 4-bp	4664 ± 399	(9)	7680 ± 151	(2)
	Pc 1-sw	721 ± 71	(10)	4312 ± 440	(10)
Cl	Hp 4-bp	2.38 ± 0.19	(8)	3.71 ± 0.16	(4)
	Pc 1-sw	4.85 ± 0.02	(3)	2.62 ± 0.37	(14)
TRP	Hp 4-bp	17.1 ± 1.9	(11)	7.08 ± 0.74	(10)
	Pc 1-sw	0.406 ± 0.041	(10)	3.94 ± 0.55	(14)
TP	Hp 4-bp	75.8 ± 6.0	(8)	1.25 ± 4.87	(4)
	Pc 1-sw	1.6 ± 0.07	(4)	28.06 ± 2.87	(10)
NH_4-N	Hp 4-bp	0.191 ± 0.04	(18)	0.778 ± 0.061	(8)
	Pc 1-sw	0.003 ±0.0002	(9)	0.039 ± 0.017	(45)
NO_3-N	Hp 4-bp	0.389 ± 0.043	(11)	0.754 ± 0.038	(5)
	Pc 1-sw	0.008 ± 0.001	(14)	0.314 ± 0.100	(32)
TKN	Hp 4-bp	1.53 ± 0.11	(7)	3.22 ± 0.069	(2)
	Pc 1-sw	0.069 ± 0.001	(2)	1.11 ± 0.100	(9)
DOC	Hp 4-bp	41.3 ± 2.50	(6)	49.4 ± 0.98	(2)
	Pc 1-sw	1.66 ± 0.023	(1)	35.6 ± 0.31	(9)
Fe	Hp 4-bp	1.96 ± 0.126	(6)	3.02 ± 0.119	(4)
	Pc 1-sw	0.011 ±0.0004	(4)	0.458 ± 0.039	(9)
K	Hp 4-bp	1.22 ± 0.096	(8)	2.26 ± 0.065	(3)
	Pc 1-sw	0.172 ± 0.005	(3)	0.643 ± 0.080	(12)

Table 7 Comparison of daily discharge estimates calculated by four different methods for Hp 4-13 and Pc 1-08 calibrated microcatchments during 1987 and 1988. Note the different number of days. r = correlation between daily estimates calculated by continuous stage record and the other 3 methods. St. Error and % ERR are defined as the deviation between the results of a given method and the results of the continuous stage record.

Method	Daily Discharge (L/S) x	± SD	Intercept	Slope	r	± St. Error (SE)	% ERR	Low Flow[1] ± SE	Low Flow[1] % ERR	High Flow[2] ± SE	High Flow[2] % ERR
Hp 4-13 (n=380)											
Continuous Stage Rec.	9.02	± 16.0	-	-	-	2.34*	19*	-	-	-	-
Integrating Discrete Dis.	9.67	± 16.8	-0.4330	0.978 ± .008	0.987	2.86	67	0.128	98	3.39	49
Regression	9.03	± 16.8	0.000	0.999 ± .007	0.990	2.33	247	1.25	455	2.64	53
Prorating Unit Runoff	8.24	± 16.4	0.052	1.089 ± .008	0.990	2.82	207	1.11	381	3.26	46
Pc 1-08 (n=486)											
Continuous Stage Rec.	0.551	± 1.22	-	-	-	2.70*	21*	-	-	-	-
Integrating Discrete Dis.	0.518	± 1.39	0.185	0.713 ± 0.023	0.812	0.816	98	0.058	51	1.05	124
Regression	0.551	± 1.22	-0.000	0.999 ± 0.014	0.956	0.358	39	0.072	85	0.461	27
Prorating Unit Runoff	0.538	± 1.23	0.043	0.945 ± .013	0.946	0.365	28	0.038	47	0.470	28

* calculations based on stage-discharge curve (Appendix II).
[1] low flow is <0.06 L/S in Hp 4-13, <0.1 L/S in Pc 1-08
[2] high flow is ≥0.6 L/S in Hp 4-13, >0.1 L/S in Pc 1-08

Table 8 Comparison of annual and monthly water loads calculated by four different methods for Hp 4-13 and Pc 1-08 calibrated microcatchments, 1987/88 water year. % ERR as described in Table 1.

		Monthly Runoff			
				FLOW	
Site Method	Annual Runoff (mm)	± % ERR	Range	<1.5 m % ERR	≥1.5 m % ERR
Hp 4-13					
Continuous Stage Rec.	476 ± 9	-	-	-	-
Integrating Discrete Dis.	510 ± 7 (7%)	20	-7 to 52	32	12
Regression	473 ± 25 (-1%)	200	-19 to 462	396	33
Prorating Unit Runoff	432 ± 23 (-9%)	168	-26 to 390	332	29
Pc 1-08					
Continuous Stage Rec.	460 ± 13	-	-	-	-
Integrating Discrete Dis.	434 ± 6 (-6%)	27	-71 to 35	0	31
Regression	461 ± 35 (<1%)	37	-59 to 100*	58	25
Prorating Unit Runoff	456 ± 13 (-1%)	32	-11 to 100*	58	18

* observed discharge = 0.0

Table 9 Areal runoff (mm) estimates for Harp 4 and Plastic 1 subcatchment and selected microcatchments, 1987/88. See Table 1 and text for description of methods.

Sub-Catchment	**Microcatchment**							
Method	**(C)**	**(R)**	**(D)**	**(R)**	**(D)**	**(R)**	**(D)**	**(R)**
Harp 4 (119.09 ha)	Hp 4-13 (61.51 ha)			Hp 4-14 (3.74 ha)		Hp 4-15 (6.07 ha)		Hp 4-18 (38.21 ha)
432	476 (10%)	473 (10%)	510 (18%)	404 (-7%)	439 (2%)	412 (-5%)	507 (17%)	465 (8%)
Plastic 1 (23.35 ha)	Pc 1-08 (3.45 ha)			Pc 1-04 (5.28 ha)		Pc 1-A (1.88 ha)		Pc 1-04 & Pc 1-A (7.16 ha)
454	460 (1%)	470 (4%)	435 (-4%)	107 (-76%)	125 (-72%)	- -	188 (-56%)	141 (-69%)

$$\% \text{ difference} = \frac{\text{microcatch. - subcatch.}}{\text{subcatch.}} * 100$$

(C) calibrated weir
(R) regression
(D) discrete measurements

Table 10 Comparison of annual and monthly total phosphorous (TP) loads calculated by four different methods for Hp 4-13 and Pc 1-08, 1987/88.

Site / Method	Annual Phosphorous Load $g/m^2\ yr^1$	± % ERR	Monthly Phosphorus Load: Range %	FLOW: < 1.5 m % ERR	FLOW: ≥ 1.5 m % ERR
Hp 4-13					
Continuous Stage Rec.	7.78	-	-	-	-
Integrating Discrete Dis.	8.44 (8%)	22	-8 to 50	30	18
Regression	8.56 (10%)	205	-19 to 461	404	38
Prorating Unit Runoff	7.77 (<1%)	172	-26 to 388	339	33
Pc 1-08					
Continuous Stage Rec.	0.917	-	-	-	-
Integrating Discrete Dis.	0.880 (-4%)	35	-107 to 29	0	40
Regression	0.916 (<1%)	40	-65 to 100*	58*	31
Prorating Unit Runoff	0.888 (-3%)	34	-8 to 100*	58*	20

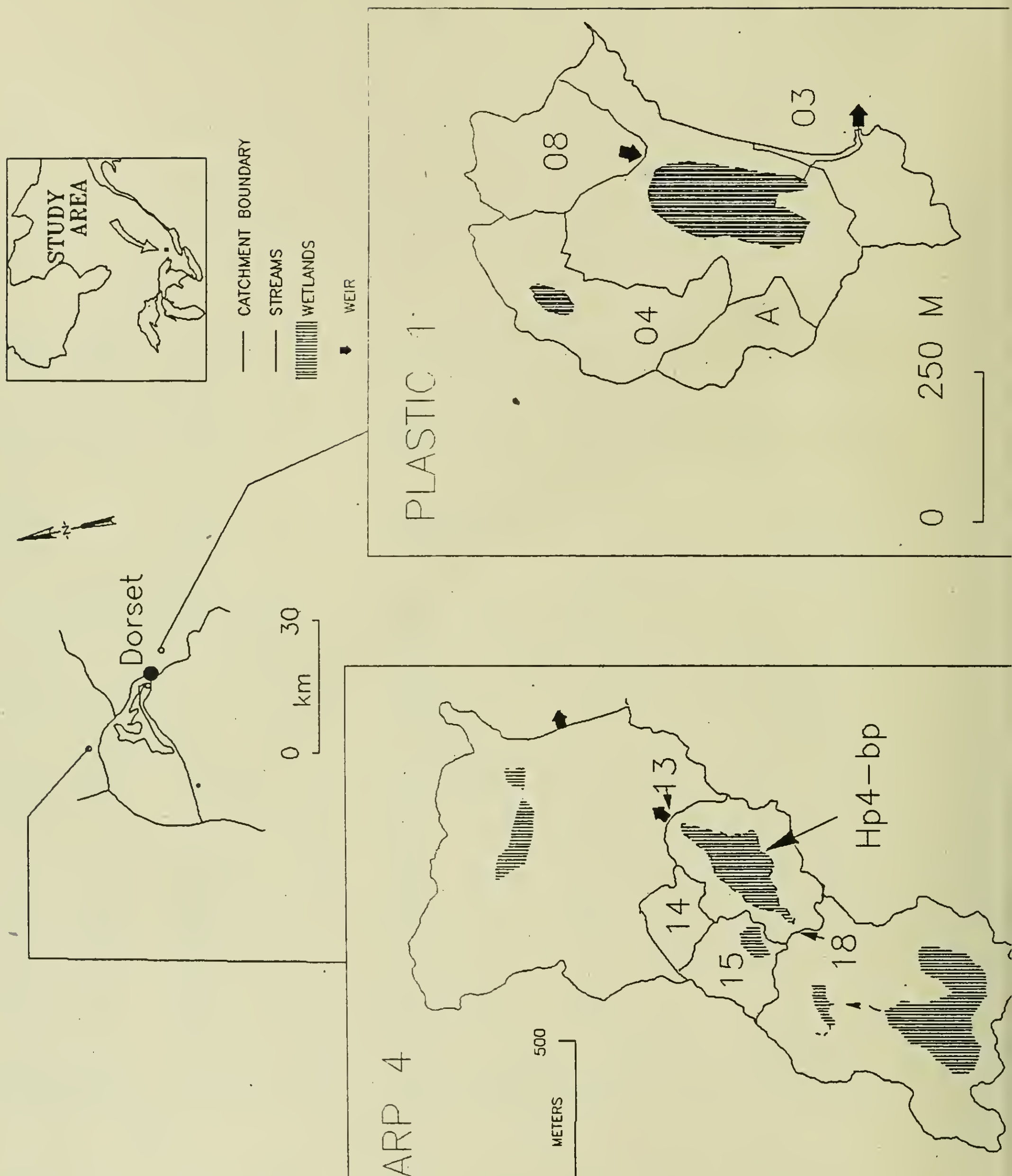
* observe load = 0.0

Table 11 Water and chemical budgets of Hp 4-bp and Pc 1-sw for 1987/88 calculated using estimates (BEST) of runoff and prorating (PRO) areal runoff for the entire subcatchment.

Parameter	Method	Harp 4 Beaver Pond g/m²	±		%	±	% Input	Plastic 1 Conifer Swamp g/m²	±		%	±	% Input
Water	BEST	258	±	504	3	±	6	516	±	600	11	±	13
	PRO	468	±	1190	6	±	15	468	±	510	10	±	11
Chloride	BEST 0.075	±	0.289	2	±	80.000		±	0.544	0			
	PRO	0.088	±	0.577	6	±	39	0.370	±	0.441	12	±	14
Total Reactive Phosphorous	BEST 0.017	±	0.002	71	±	80.004		±	0.001	53	±	13	
	PRO	0.018	±	0.004	71	±	16	0.005	±	0.001	53	±	11
Total Phosphorous	BEST -0.012	±	0.011	-11	±	10.001		±	0.005	4	±	20	
	PRO	-0.006	±	0.020	-5	±	17	0.003	±	0.005	9	±	15
Ammonium (NH_4-N)	BEST -0.062	±	0.078	-9	±	10.338		±	0.030	90	±	8	
	PRO	-0.064	±	0.109	-10	±	17	0.339	±	0.025	90	±	7
Nitrate (NO_3-N)	BEST	0.399	±	0.091	35	±	8	0.321	±	0.078	51	±	12
	PRO	0.392	±	0.121	37	±	11	0.323	±	0.048	51	±	8
Total Organic Nitrogen	BEST	-0.535	±	0.179	-28	±	9	-0.494	±	0.157	-79	±	25
	PRO	-0.486	±	0.404	-27	±	22	-0.416	±	0.129	-59	±	18
Total Nitrogen	BEST	-0.196	±	0.186	-5	±	5	0.165	±	0.174	4	±	4
	PRO	-0.158	±	0.407	-2	±	5	0.247	±	0.135	6	±	3
Dis. Organic Carbon	BEST	-1.32	±	3.16	-3	±	7	-20.3	±	5.4	-133	±	35
	PRO	3.11	±	7.19	1	±	2	-17.3	±	3.6	-94	±	20

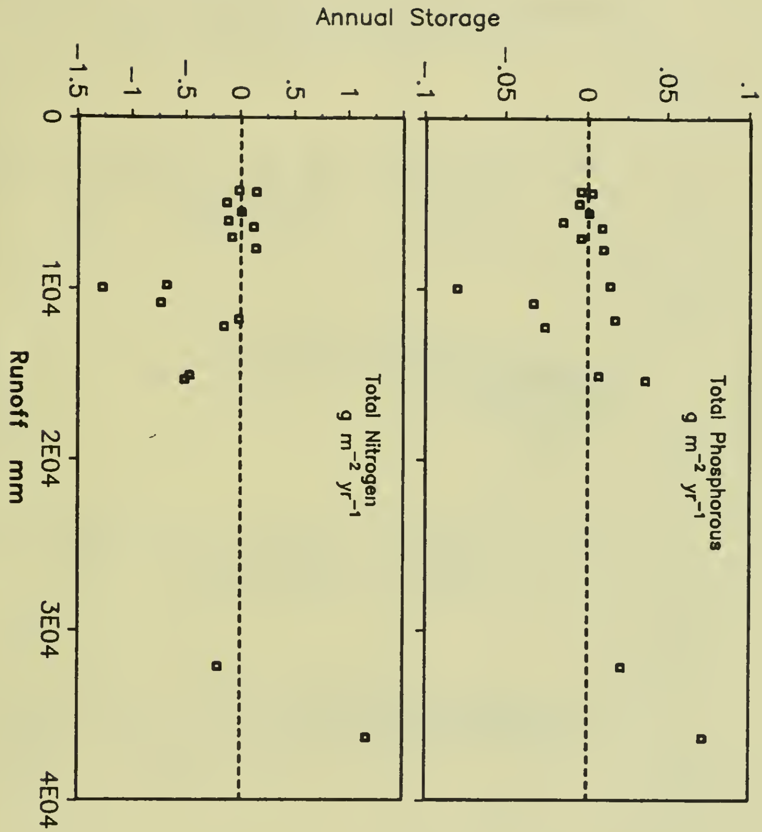
Table 12 Monthly water and total phosphorous (TP) budgets for Hp 4-bp and Pc 1-sw for August 1987 and April 1988 using best (BEST) estimates of runoff and prorating (PRO) areal runoff for the entire subcatchment.

Parameter		Input			Output	Retention	
Month	Method	Stream Flow	Ungauged	Precip-itation	Stream Flow	Absolute	% ± % ERR of Input
Harp 4 Beaver Pond							
Water (mm)							
Aug 87	BEST	7 ± 1	0	67 ± 14	13 ± 1	61 ± 16	82 ± 22
	PRO	38 ± 7	0	67 ± 14	62 ± 18	43 ± 24	41 ± 23
Apr 88	BEST	2752 ± 357	572 ± 178	87 ± 18	3473 ± 133	-62 ± 421	-2 ± 14
	PRO	2489 ± 363	497 ± 164	87 ± 18	3193 ± 927	-121 ± 1009	-4 ± 33
Total Phosphorus (mg/m^2)							
Aug 87	BEST	0.001 ± 0.000	0.000	0.002 ± 0.000	0.001 ± 0.000	0.002 ± 0.001	73 ± 37
	PRO	0.004 ± 0.002	0.000	0.002 ± 0.000	0.004 ± 0.001	0.002 ± 0.002	33 ± 33
Apr 88	BEST	0.031 ± 0.005	0.002 ± .001	0.002 ± 0.001	0.039 ± 0.004	-0.004 ± 0.007	-11 ± 19
	PRO	0.029 ± 0.008	0.001 ± .001	0.002 ± 0.001	0.036 ± 0.012	-0.004 ± 0.014	-13 ± 44
Plastic 1 Conifer Swamp							
Water (mm)							
Aug 87	BEST	0	0	67 ± 14	0	67 ± 14	100 ± 21
	PRO	0	0	67 ± 14	0	67 ± 14	100 ± 21
Apr 88	Best	715 ± 43	1190 ± 357	87 ± 18	2281 ± 411	-289 ± 546	-15 ± 27
	PRO	956 ± 123	1086 ± 326	87 ± 18	2281 ± 411	-152 ± 539	-8 ± 25
Total Phosphours (mg/m^2)							
Aug 87	BEST	0.000	0.000	0.002 ± 0.000	0.000	0.002 ± 0.001	100
	PRO	0.000	0.000	0.002 ± 0.000	0.000	0.002 ± 0.001	100
Apr 88	BEST	0.003 ± 0.001	0.003 ± .001	0.002 ± 0.001	0.013 ± 0.003	-0.005 ± 0.004	-63 ± 50
	PRO	0.003 ± 0.001	0.002 ± .001	0.002 ± 0.001	0.013 ± 0.003	-0.006 ± 0.004	-86 ± 57



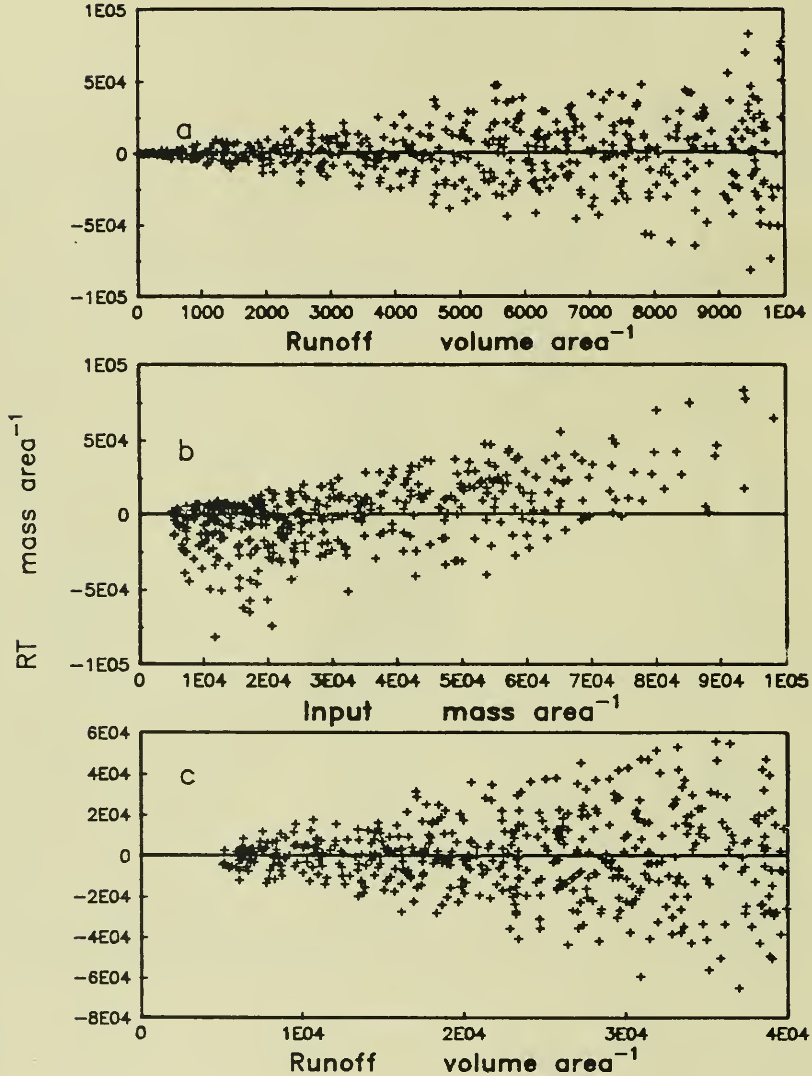
STUDY AREA
CATCHMENT BOUNDARY
STREAMS
WETLANDS
WEIR
N
Dorset
0 km 30
PLASTIC 1
08
03
04
A
0 250 M
HARP 4
Hp4-bp
13
14
15
18
0 METERS 500

Figure 1



Annual Storage
Total Phosphorous
g m-2 yr-1
Total Nitrogen
g m-2 yr-1
Runoff mm
0
1E04
2E04
3E04
4E04
.1
.05
0
-.05
-.1
1
.5
0
-.5
-1
-1.5

Figure 2



a
b
c
1E05
5E04
0
-5E04
-1E05
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
1E04
Runoff volume area^{-1}
RT mass area^{-1}
1E04
2E04
3E04
4E04
5E04
6E04
7E04
8E04
9E04
1E05
Input mass area^{-1}
6E04
4E04
2E04
-2E04
-4E04
-6E04
-8E04
Runoff volume area^{-1}

Figure 3

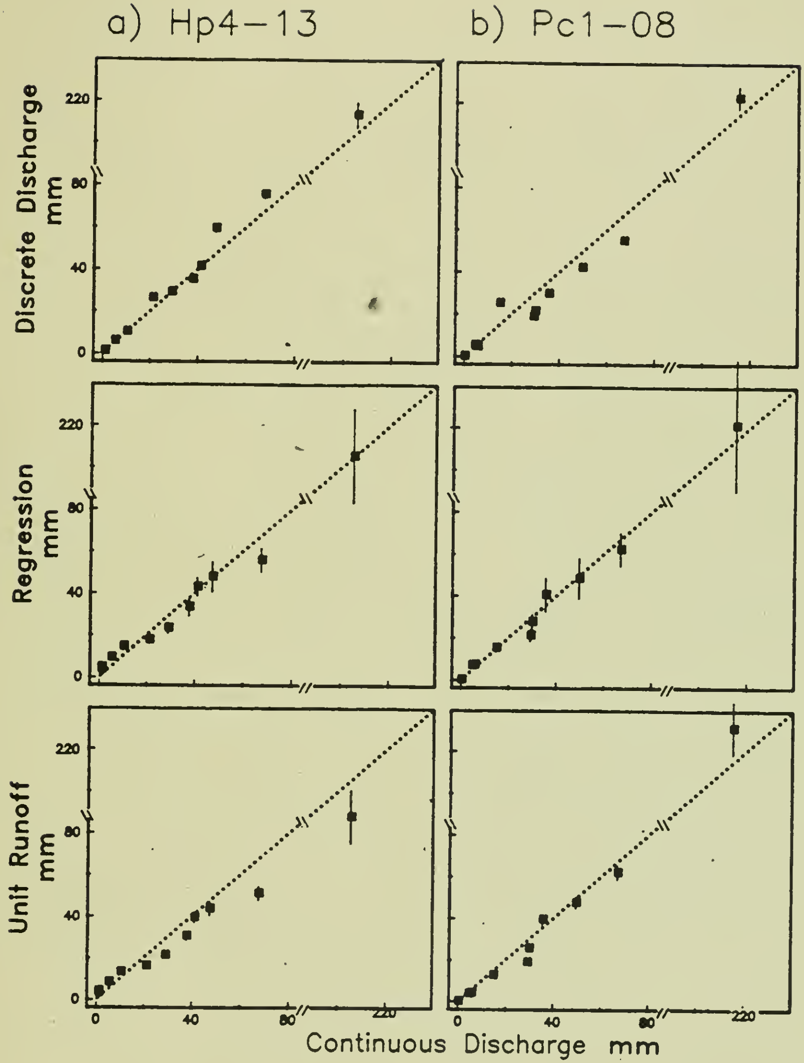

a) Hp4-13
b) Pc1-08
Discrete Discharge
mm
Regression
mm
Unit Runoff
mm
0
40
80
220
Continuous Discharge mm

Figure 4

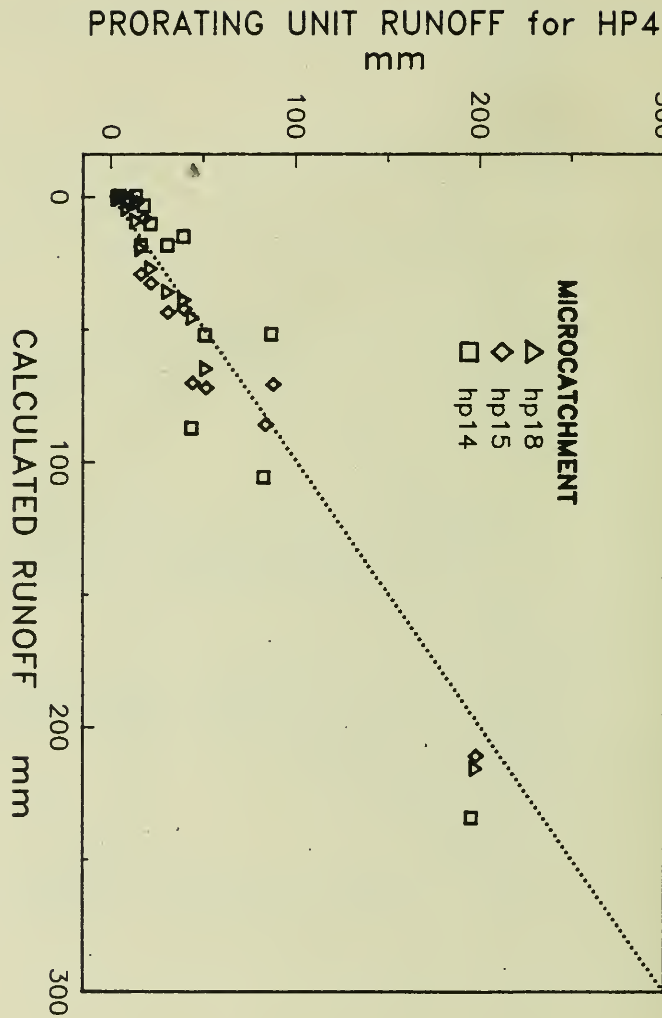

PRORATING UNIT RUNOFF for HP4
mm
0
100
200
300
MICROCATCHMENT
hp18
hp15
hp14
CALCULATED RUNOFF mm

Figure 5